2 Introduction

This report presents FEMA's Building Performance Assessment Team's (BPAT) observations on the success and failure of buildings in Puerto Rico to withstand the wind and flood forces generated by Hurricane Georges. In addition, the seismic resistance of some of the buildings observed was assessed. In this report, "buildings" refer to single- and multifamily homes, residential buildings, and commercial and industrial buildings. Recommendations to improve building performance in future natural disasters in Puerto Rico are included. During this building performance assessment, additional consideration was given to mitigation success stories, particularly when mitigation successfully reduced damages. In the context of this document, mitigation is defined as actions taken to prevent building damage and/or minimize the extent and impact of building damage if it occurs.

A separate team has prepared a BPAT report on the effects of Hurricane Georges in the Gulf Coast of the United States. A copy of the Gulf Coast BPAT report is available from FEMA by contacting FEMA's Publication Distribution Center at (800) 480-2520, and requesting FEMA Publication #338, or it may be downloaded from the World Wide Web at www.fema.gov.

2.I Background of Storm

Historical data indicate that the island of Puerto Rico has been struck or otherwise affected by 10 hurricanes since 1893 [Defensa Civil Estatal de Puerto Rico and FEMA 1996]. Their intense rain and devastating wind speeds have caused extensive damage to the island. Figure 2-1 shows the path of these hurricanes. Hurricane category designators in Figure 2-1 (e.g., CAT 2) are based on the Saffir-Simpson scale. Central pressure of the hurricane (measured in millibars) and wind speed (measured in mph as 1-minute sustained) ranges for hurricane categories of the Saffir-Simpson scale are shown in Table 2-1.

Hurricane Georges formed 400 miles south-southwest of the Cape Verde Islands and moved across the Atlantic into the Caribbean on September 16, 1998. It made landfalls in the West Indies; Virgin Islands; Puerto Rico; Hispanola, Cuba; the Florida Keys, the Chandeleur Islands of Louisiana, and coastal Mississippi. Hurricane Georges was upgraded September 17 to a Category 4 hurricane as it moved west through the Caribbean packing 150-mph winds over open water. The storm was downgraded to a Category 2 once it moved through the Leeward, U.S. and British Virgin Islands on September 21. The storm was categorized as a tropical storm late afternoon on September 28. Wind speeds are further discussed in Section 3.1.

¹ The Saffir-Simpson hurricane scale ranks hurricanes by categories (CAT). These categories are based on the central pressure of the hurricane and wind speed (measured as 1-minute sustained).

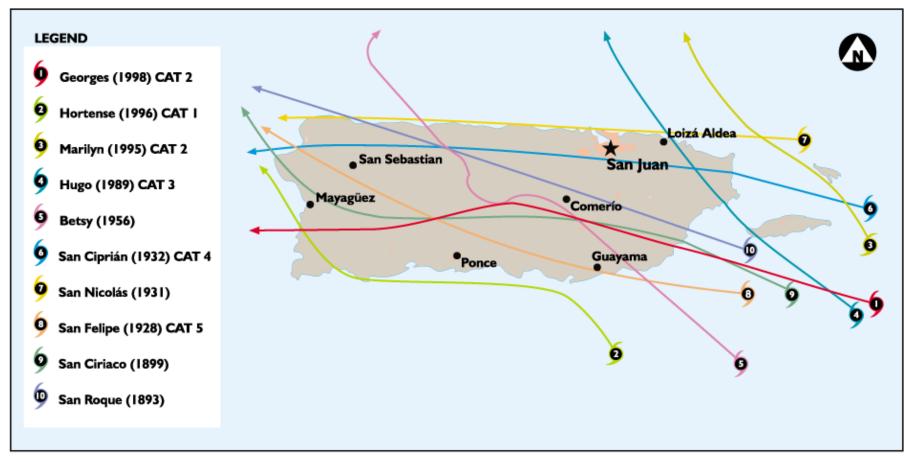


FIGURE 2-1 History of hurricanes in Puerto Rico.

Source: Huracanes en Puerto Rico: Guía de Mitigación de Danõs.

Category (CAT)	Central Pressure	Wind Speed (I-min. sust.)
I	>980 mb	74 mph - 95 mph
2	965 - 980 mb	96 mph - 110 mph
3	945 - 965 mb	III mph - I30 mph
4	920 - 945 mb	131 mph - 155 mph
5	<920 mb	>155 mph

TABLE 2-1 Pressure and wind ranges for hurricane categories of the Saffir-Simpson Scale.

On the evening of September 21, 1998 Hurricane Georges made landfall on Puerto Rico's east coast as a strong Category 2 hurricane. The storm passed off the west coast of the island September 22, most probably as a weak Category 2 hurricane. It traveled directly over the island, mainly in an east-west direction. Puerto Rico had not experienced a hurricane of this magnitude since Hurricane Hugo, a devastating Category 3 hurricane that passed over the northeast corner of Puerto Rico in a southeast to northwest direction in September 1989. The only Category 4 and 5 hurricanes to strike the island this century were San Ciprían (Category 4, September 1932) and San Felipe (Category 5, September 1928). Prior to Hurricane Georges, the last hurricane to hit Puerto Rico was Hortense, which was a Category 1 hurricane when it passed over the southwest corner of the island in September 1996.

Rainfall from Hurricane Georges exceeded 18 inches at the center of Puerto Rico at Jayuya. The highest recorded level was east of Jayuya at Comerío, which received almost 26 inches of rain during the two-day period of the storm. Three deaths were directly attributed to Hurricane Georges in Puerto Rico and nine others occurred from medical complications [National Oceanic and Atmospheric Administration (NOAA) 1998].

Hurricane Georges caused extensive damage in Puerto Rico. It was the costliest disaster ever for the American Red Cross, which has spent \$104 million for recovery in the Caribbean and United States combined [*New York Times* 1998]. Approximately 80 percent of Puerto Rico's 3.8 million people were without power and water at some point during the storm. Over 30,000 homes were destroyed and 50,000 more experienced major or minor damage. Hurricane Georges destroyed 75 percent of the country's coffee crop, 95 percent of Puerto Rico's plantains, and 65 percent of its chickens [NOAA 1998].

2.2 Team Composition

On September 30, the FEMA Mitigation Directorate deployed the BPAT to Puerto Rico to assess damages caused by Hurricane Georges. The team included architects, engineers, planners, floodplain management specialists, and insurance specialists. See Appendix A.

The BPAT's mission was to assess the performance of buildings throughout Puerto Rico and make recommendations for improving building performance in future events. The BPAT process is intended to provide the government of Puerto Rico, local governments, and other interested parties guidance for post-hurricane reconstruction with the goal of enhancing the performance of buildings exposed to future natural hazards.

Aerial and ground site investigations were conducted to observe building conditions in selected areas affected by the storm. The mission did not include recording the number of buildings damaged by Hurricane Georges, determining the frequency of specific types of damage, or collecting data that could serve as the basis of statistical analysis. Collectively, the team has invested more than 1,000 hours to date conducting site investigations, inspecting damages, and preparing documentation. Documentation included field notes and photographs.

Field investigations of significantly damaged areas mainly focused on one- to two-story buildings (homes). However, some essential facilities and high-rise commercial and industrial buildings were also assessed and are included in this report.

2.3 Methodology

The BPAT conducted two aerial assessments of Puerto Rico. The first passed through Canóvanas, Humacao, Caguas, Jayuya, Adjuntas, Utuado, Aguadilla, Rincón, Mayagüez, Cabo Rojo, Ponce, and Toa Baja. A second flyover of east Puerto Rico included Fajardo and the two islands to the east: Vieques and Culebra (Figure 2-2).

Field investigations began on October 4 and lasted until October 9. Wind and flood damage and success stories were gathered and local residents were interviewed. Power poles, as well as other infrastructure items, were also inspected to determine the effects of the storm.

On October 6, the BPAT split into two groups, a wind investigation team (Wind Team) and flood investigation team (Flood Team). Ground investigations for both groups included visits to Jayuya, Adjuntas, and Utuado (Figure 2-3). On October 7, the Flood Team continued west investigating coastal and riverine flooding in Cabo Rojo, Rincón, Mayagüez, Aguadilla, and Arecibo. The Wind Team remained in the center of the island north of Ponce to observe wind damage and investigate reports of tornadic activity. On October 9, both teams flew to Culebra to inspect this newly designated FEMA Project Impact community.² The BPAT team completed its deployment on October 10.

2.4 Planning Regulations

Planning Regulation 7 (building code) was first adopted by the Government of Puerto Rico in 1968 and was later amended in 1987. The "provisions on the minimum loads for calculation of [loads acting on] structures were completely revised, taking into consideration the requirements of the 1982 Uniform Building Code (UBC) and recommendations of the study carried out by the Commission on Earthquakes of the Engineers and Surveyors Association of Puerto Rico," according to the amended regulations. As part of the 1987 Planning Regulation amendment, Puerto Rico was identified as a seismic zone 3, requiring all new construction—single-family houses included—to be seismic-resistant. A design wind speed of 110 mph (fastest-mile) was recommended. Puerto Rico's Regulations and Permitting Administration (Adminstración de Reglamentos y Permisos [ARPE]) regulates these provisions of Planning Regulation 7, which was in effect at the time Hurricane Georges struck

² FEMA's Project Impact Program helps communities protect themselves from the devastating effects of natural disasters by taking actions that dramatically reduce the potential for disruption and loss to buildings and property. FEMA provides expertise and technical assistance from the national and regional levels (including other federal and state agencies) to individual communities to mitigate against natural hazard events and provide funding for the administrative support of these initiatives.



FIGURE 2-2 Flyover routes from October 2 (in red) and October 3 (in blue). Map is not to scale. Source: The Perry Castañeda Library Map Collection.



FIGURE 2-3 Locations of ground investigation by the BPAT. Map is not to scale.

Puerto Rico. In late December 1998, the government of Puerto Rico adopted emergency regulations to repeal Planning Regulation 7 and adopt the 1997 Uniform Building Code (UBC) as the building code of Puerto Rico.

2.5 Floodplain Management Regulations

In August 1978, the Government of Puerto Rico joined the National Flood Insurance Program (NFIP). The NFIP was created by an act of the U.S. Congress to make flood insurance available to property owners in communities that agree to enact and administer floodplain management regulations meeting program requirements. Initial Flood Insurance Rate Maps (FIRMs) of Puerto Rico were issued in August 1978; the most recent updates were published in September 1996.

The Government of Puerto Rico adopted NFIP-compliant floodplain management provisions under Planning Regulation 13 to regulate construction in Special Flood Hazard Areas (SFHAs) identified as flood zones on FIRMs. In coastal areas, this means that buildings must be adequately elevated and protected from the effects of high-velocity flood flow. In V-Zones, buildings must be elevated on piling (or column) foundations and the lowest horizontal structural member of the lowest floor must be at or above the Base Flood Elevation (BFE). In addition, the area below the building must be free of obstructions or enclosed by non-supporting breakaway walls intended to collapse under wind and water loads without causing damage to the foundation or the elevated portion of the building.

In A-Zones, which are less likely to be affected by high-velocity flow, the top of the lowest floor of the building must be at or above the BFE and the areas below the BFE can be enclosed with non-breakaway walls. However, the area below the BFE can only be used for parking, access, and storage. These regulations require new and substantially improved buildings in floodprone areas to be built to reduce flood hazards. The Puerto Rico Planning Board and ARPE regulate Planning Regulation 13.

2.6 Puerto Rico Seismicity

Along with much of the Caribbean, Puerto Rico is subject to significant earthquake and tsunami risk. The written history of earthquake damage in Puerto Rico dates back to 1867 when the first earthquake was recorded, with an estimated magnitude of 7.3 on the Richter Scale occurring off southeast Puerto Rico. In 1918, the island was hit by a magnitude 7.3 earthquake approximately 9 miles off its northwest coast. The ensuing tsunami had wave heights approaching 19 feet and caused major damage. Reportedly, 116 people were killed, 40 as a direct result of the tsunami. A minor earthquake also hit the island in 1922 [Earth Scientific Consultants]. The American Society of Civil Engineers Standard 7-95 (ASCE 7-95), *Minimum Design Loads for Buildings and Other Structures*, as well as the National Earthquake Hazards Reduction Program (NEHRP) 1997 Recommended Provisions, require all structures in Puerto Rico, including single family homes, to be seismic resistant. These documents have stricter requirements for seismic construction in Puerto Rico than Planning Regulation 7 (building code) that was in place when Hurricane Georges struck Puerto Rico. The recently adopted 1997 UBC is compliant with both the 1997 NEHRP and the seismic provisions of ASCE 7-95.